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Attenuation of High Intensity Reradiated Light by Photochromic Glass

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One possible threat mechanism by which High Energy Laser Weapons may exploit the vulnerability of U.S. Army systems is through the production of large fluences of reradiated visible light when glass surfaces such as windscreens, vision blocks or lenses are struck by pulsed or cw laser radiation. At 10.6 meter laser wave lengths silicate glasses have very shallow absoprtion depths and, hence, heat to incandescence rapidly. Such blackbody surfaces at temperatures of 3000°C will reradiate strongly in the visible region of the spectrum. In addition, if pulsed laser conditions are such that air plasmas are formed on the target, blackbody temperatures of 17,000°C may be obtained.

In both the cw and the pulsed laser cases, the net flux obtained in the visible region will be a complicated function of fluence on target, target material, pulse shape and other parameters. Net dosage delivered to the retina and, hence, available for flashblinding will also depend on fluence rise times and blink reflex times.

This paper does not attempt to address flashblindness conditions; rather it focuses on the enhanced attenuation of the visible light in the optical materials behind the target surface.

Glasses which are prepared with certain metal salts and oxides may be photochromic, i.e., irradiation at specific absoption band wave lengths will electronically excite "color center" sites producing typically, holes and reduced metal atoms. Such activated sites will absorb radiation over a broad wavelength throughout the visible and near infrared regions of the spectrum. Visually, the materials darken under appropriate radiation. Excitation wavelengths are in the ultraviolet.

The detailed behavior of such photochromic glasses depends on both the composition and processing history of the glass. All of the revellant photochromic properties such as, activation band, absorption spectrum, rate of formation and bleaching rate vary with composition and processing. These may be chosen to emphasize one or more desired glass properties such as, optical density, darkening rate or bleaching time. Generally, the properties are not independent.

This paper reports a set of experiments to test the concept of the photochromic glass response as countermeasure against the visible reradiation obtained when transparent materials are irradiated by high energy lasers. In all of the experiments, a fused silica face plate (chose because of ultraviolet (uv) transparency) was the target and a laminate of four layers of the photochromic glass was placed behind the fused silica. Attenuation of visible light traversing the photochromic glass was measured.

The photochromic glass used in the experiment was a conventional silver halide composition prepared by PPG and supplied for the experiments by Dr. Herbert D. Kivlighn of Grumman Aerospace Corporation. The glass had been one of several investigated in an unrelated program at Grumman and had been chosen for its ready availability and not for any particular photochromic property. In separate calibration experiments performed by Grumman excitation radiation in the 300 to 400 mm band, particularly between 320 and 360 mm caused photochromic darkening of the glass. Rate of darkening was dependent on excitation intensity.

AMMRC conducted laser irradiation experiments. These were performed on both cw and pulsed CO_2, 10.6 μm lasers. The pulsed laser employed was the "Humdinger" laser at Arco-Everett Research Laboratory in Everett, Massachusetts and the experiments were caried out under the auspices of the Joint Army, Navy, Air Force (JANAF) repetitively pulsed high energy laser test program. Vulnerability, effects and hardening experiments, with high energy lasers have been carried out under this program for several years. These photochromic glass experiments were carried out as part of the Army high energy laser hardening program under AMMRC auspices. The cw laser experiments were conducted at NARADCOM, Natick, Massachusetts where Natick Laboratories operates a 1.5 Kw cw CO_2 laser. AMMRC and NARADCOM have a joint program for the use of this laser.

Attenuation measurements were made by passing a HeNe laser beam through the photochromic glass during CO_2 laser irradiation and measuring the intensity of the transmitted light with a PIN diode. Care was taken to remain in the linear portion of the measurement system response Because of the restricted geometry of the pulsed laser, experimental arrangements only transverse measurements were made. That is while the laser was incident normal to the fused silica faceplate, a HeNe beam transversed the photochromic layer of interest in the plane perpendicular to the pulsed CO_2 beam. The HeNe beam was manipulated with a set of mirror reflectors and placed so it measured absorption along some convenient path through the first layer of photochromic glass.

Pulsed laser flux was focused so that plasma formation threshold was exceeded. The beam was collimated so that only 3 cm^2 of the fused silica faceplate were exposed to the air plasma. Laser pulse lengths and repetition rates were held fixed to values deemed appropriate from propagation analysis. An infrared detector monitored front face temperature. Both this device and a still camera confirmed plasma formation.

Front face damage of the fused silica faceplate confirmed the existence of high temperatures during the laser runs.

Due to program limitations, only two pulsed CO_2 laser shots were available. Timing sequence equipment failure caused the loss of motion picture coverage on one of the two shots. The high speed motion picture film of the other shot clearly shows photochromic response during the pulse train as shown in figure 1. The PIN diode output showed optical attenuation during each pulse train with more than 90% reduction of optical flux in less than one blink reflex time. Significant attenuation occurred during the first pulse.

The photographs shown in figure 1 are taken from the high speed motion picture film of the second laser shot. The darkening of the glass as seen in the film, qualitatively confirms the measurements obtained from the PIN diode attenuation experiment.

The conclusion to be drawn based on the pulsed CO_2 experiments is that photochromic glasses are a candidate passive countermeasure material for situations in which laser induced air plasmas constitute a threat to visual or optical systems.

Cw laser experiments were conducted on the same materials at U.S. Army Natick Laboratories (NARADCOM) using the 1.5 K Watt CO_2 laser system sponsored by AMMRC.

A large number of tests were performed at various fluence levels and for various irradiation times. Since the laser output could be focused it was possible to make measurements at various heating rates for the fused silica surface. Focusing enabled high temperatures to be reached. Silica deposits indicated that surface temperatures in excess of $2600^{o}K$ were achieved. It is not unlikely that the vapor was heated to temperatures of $3000^{o}K$ and above.

At a temperature of $3000^{o}K$, blackbody flux is between 1 and 10 $mWatt/cm^2$ the photochromic excitation band. These fluences are sufficient to trigger photochromic response under normal circumstances. Measurements made of the uv flux radiated from the front surface of the laser heated fused silica demonstrated that sufficient intensity was available to trigger the response.

HeNe measurements made in the same fashion as those described earlier for the pulsed laser case determined visible light attenuation during and after irradiation by the CO_2 laser beam. Because there was less experimental constraint in the case of these cw laser experiments, it was possible to measure attenuation of transmitted light in directions both transverse to and parallel to the CO_2 laser beam direction. The measurements were consistent with one another; there was not unexpected enhancement of attenuation that was not caused by geometry or non-uniform irradiation. The magnitudes of attenuation measured in both directions were likewise consistent.

Because of the limited power output of the cw laser available, it was not possible to irradiate the fused silica at fluences sufficient

to cause incandescence in times less than the blink reflex time of the human eye. However, the experiment did demonstrate that when uncomfortable levels of visible reradiated light were achieved sufficient photochromic response was obtained to cause substantial attenuation of the visible light. In each case measured, the attenuation of the transmit- visible flux increased at qualitatively the same rate as the visible flex transmitted through the photochromic glass remained approximately constant.

HeNe measurements were made in each of the several layers of photochromic glass to measure the diminuation of photochromic attenuation as excitation flux dropped. Results were consistent with a model which assumed the excitation radiation to fall off exponentially because of absorption in depth.

Bleaching rates as a function of temperature were measured in the cw laser experiments. These indicated that bleaching times were sufficiently short that full transmission could essentially be achieved in less than 3 seconds after irradiation had ceased. Observations during the pulsed laser experiments indicated that bleaching times were likewise short.

The overall conclusion based on both sets of experiments is that photochromic glass offers the possibility of a countermeasure for laser tactics which rely on the blinding of sensors and observers due to visual optical flux generated by heated surfaces or air plasmas.

Figure 1a. Photochromic Glass Before Pulsed Laser Irradiation

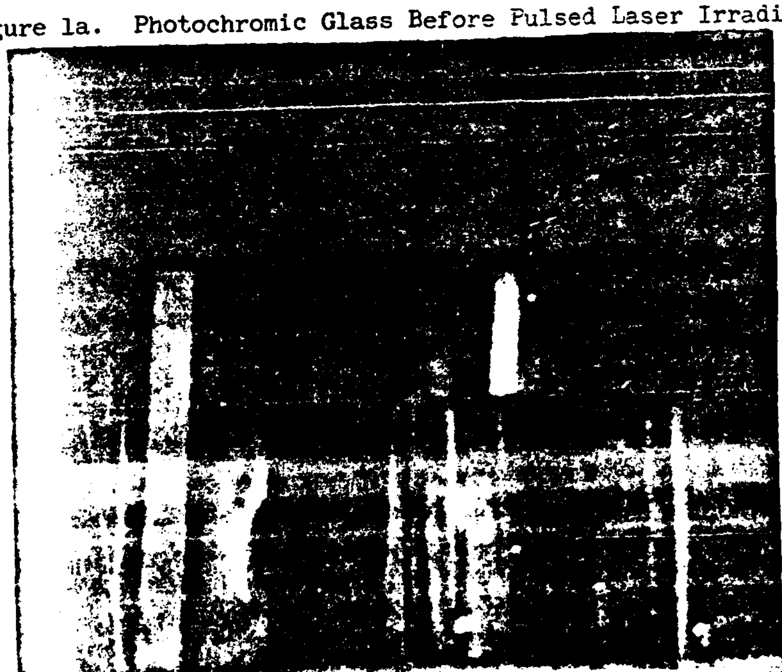

Figure 1b. Photochromic Glass After Pulsed Laser Irradiation